Electron Cloud related Beam Instabilities

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Main issues

1. **Electron cloud (EC) beam instability criteria are agreeable with the EC induced coherent tune shift. The growth rate for RHIC gold beam at the transition is in the order of ms.**
2. **Electron cloud induced incoherent tune spread offsets the space charge tune spread, and may reduce the Landau damping.**
3. **Measured RHIC impedance is larger than the expected. However, impedance is still too low to explain the fast transverse instability.**
4. **Better diagnostics is needed. If EC is a dominant factor in transverse instabilities, then Solenoid may help.**

I. EC induced coherent tune shift and instability criteria

- **For the usual electron density $\rho_e = 10^{12} m^{-3}$, electron cloud induced coherent tune shift is**

$$\Delta\nu_{coh,EC} = \frac{\rho_e r_{Au} C\bar{\beta}}{2\gamma}$$

where r_{Au} is the classical radius for gold per charge, C is the machine circumference, and $\bar{\beta}$ is the average beta function. For RHIC at injection and transition, $\gamma = 10.5$ and 23, and $\Delta\nu_{coh,EC} = 0.0025$ and 0.0011.

- **Single bunch BBU (beam break-up) growth rate,**

$$\frac{1}{\tau_{BBU}} = \frac{2\pi\rho_e r_{Au} c\bar{\beta}}{\gamma}$$

Growth rate and tune shift are related by $1/\tau = \omega_0 \Delta\nu$. Here we have $1/\tau_{BBU} = 2\omega_0 \Delta\nu_{coh,EC}$. BBU growth rate is in line with the coherent tune shift. At RHIC injection and transition, $\tau = 0.4ms$ and $0.9ms$.

- **Including synchrotron motion, for single bunch TMCI (transverse mode coupling, or strong head-tail), electron density threshold $\rho_{e,thr}$ is shown in,**

$$\nu_S = \frac{\pi \rho_{e,thr} r_{Au} C \bar{\beta}}{2\gamma}$$

Let synchrotron tune $\nu_S = \pi \Delta \nu_{coh}$, this equation is the same as BBU criterion. At injection and transition, $f_S = 140 Hz$ and $12 Hz$, $\rho_{e,thr} = 2.3 \times 10^{11} m^{-3}$ and $4.3 \times 10^{10} m^{-3}$.

- **Consider the perturbed electron cloud affecting the following bunches. Coupled bunch instability (CB) growth rate is exactly the same as BBU. Fast beam-ion instability (FBII), is also very similar.**
- **These criteria were confirmed in some cases, but not always agreeable with machine observation. Reasons are,**
  1. **Some critical EC issues not yet clearly understood.**
  2. **Landau damping not included.**

II. Incoherent tune spread

- **Usual space charge incoherent tune spread is,**

$$\Delta\nu_{inc,SC} = \frac{-N_{tot} r_{Au} \overline{\beta}}{4\pi\gamma\sigma^2} \frac{1}{\gamma^2}$$

where N_{tot} is the total intensity, and σ is the rms beam size.

- **The electron cloud induced incoherent tune spread is,**

$$\Delta\nu_{inc,EC} = \frac{N_{tot} r_{Au} \overline{\beta}}{4\pi\gamma\sigma^2} \eta_e$$

where η_e is the local neutralization factor, usually in a range of 0.001 to 0.01. Space charge incoherent force is cancelled for $\eta_e = 0.01$ at RHIC injection, and $\eta_e = 0.002$ at transition.

- **Beam-beam incoherent tune spread per IP is,**

$$\Delta\nu_{inc,b-b} = \frac{-N_{bh} r_{Au} \beta_{x,y}}{4\pi\gamma\sigma^2}$$

If $N_{tot}\eta_e = N_{bh}$, b-b completely offsets the EC force, i.e., a bunch with the charge of N_{bh} sees the same amount of electrons in 1 turn, then collide a bunch with same intensity. b-b was used in gold operation to stabilize the beam.

- **Several important issues, such as electron density, distribution and its evolution at the bunch passing, have being discussed in PAC2001, HEACC2001, KEK two-stream workshop, 9/2001, and APAC 2001. RHIC has yet another problem, EC distribution in the ring depends on the location.**

III. RHIC fast transverse instability

- **Measured transverse impedance is larger than expected, but too low to explain the observed fast transverse instability.**
- **Using the CERN PS BBU calculation, the RHIC growth time is 100ms - 200 ms ($\Delta\nu \approx 10^{-5}$), likely to be damped.**
- **Chromaticity above transition had been tuned frequently. The chromaticity polarity is not the dominant factor in instability.**
- **Search for possible offenders.**

- **RHIC gold and proton runs vs. SPS fixed target and collider runs. In [ ], it shows the fixed target run without filling the ring.**

	SPS	RHIC	SPS	RHIC	Unit
	Fixed Target	Gold	Collider	Proton	
E_k	14	8.9	26	23.4	GeV / u
N_{bh}	1 [4]	7.9	25	20	10^{10}
τ_ℓ	3.6	20	7	20	ns
I_p	0.71 [2.8]	1.0	9.1	2.6	A
Z_V	28	3 - 5	28	3 - 5	$M\Omega / m$

E_k: **Kinetic energy.**
N_{bh}: **Bunch charge.**
τ_ℓ: **Full bunch length.**
I_p: **Peak current.**
Z_V: **Vertical impedance.**

* **RHIC gold has** $q / A = 0.4$ **factor and gamma jump.**

IV. Electron cloud concerns

- **The pressure rise, the upward tune shift, and the IPM electron background uprising at pressure rise, are the possible indications of the EC.**
- **The EC instability is mostly single-bunch (at a few hundreds MHz), but it only happens at multi-bunch injection, which generates EC. Single-multi-bunch instability. 110-bunch beam instability might be more serious than the 55-bunch.**
- **At the B factories, electron cloud aggravated the beam-beam effect, however, at the RHIC, they offset each other.**
- **Diagnostics: electron detector, coherence detector, a short stripline, and beam spectrum for incoherent tune spread.**
- **Solenoid installation is under discussion. It is expected to prevent the electron multipacting, hence to stop pressure rise. It may also help to stabilize beam.**